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TECHNOLOGY POSTER ABSTRACTS

Properties of Vapor-Deposited Au:Er Films for Metallic Magnetic Calorimeters

H. Eguchi,a R. Bruni,b Y. H. Huang, A. N. Mocharnuk-Macchia,a S. Romaine,b G. M. Seidel,a B. Sethumadhavan,a and W. Yao,a

a. Department of Physics, Brown University, Providence, RI 02912, USA
b. Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA

The next generation x-ray astronomy satellite missions such as Constellation-X will utilize a cryogenic microcalorimeter for high-energy resolution (ΔE=2~eV up to 10~keV) x-ray spectroscopy. The more recent technology, metallic magnetic calorimeters (MMCs) has shown comparable energy resolution to TES and other microcalorimeters. A prototype MMC, in which the magnetization of Au:Er sensors has been measured using a DC SQUID, have shown excellent energy resolution for soft x-rays. However, the results to date have been obtained with devices assembled by hand, placing a small (~50 μm diameter), thin disk of the Au:Er alloy within the loop of the SQUID. This is an unacceptable method for fabricating large focal-plane arrays of detectors required for the next generation of x-ray telescopes. We are therefore investigating the properties of vapor-deposited films produced by DC magnetron sputtering using an Au:Er alloy target. The magnetic properties of five micron thick Au:Er films have been investigated from room temperature down to 40 mK. The measured magnetization matches theoretical values down to 200 mK. The films have the same Er concentration as in the target material. At lower temperatures there is indication of enhanced magnetic interactions among the Er ions. We are studying the dependence of this interaction on the parameters used in the deposition process.

This work is supported by NASA grants NAG5-10383 and APRA04-0000-0157

Large Field of View for Constellation-X with Position-Sensitive Transition-Edge Sensors

E. Figueroa-Feliciano, S. R. Bandler, J. Chervenak, F. Finkbeiner, A. Hornschemeier, N. Iyomoto, R. L. Kelley, C. A. Kilbourne, F. S. Porter, J. Sadleir, J. White

The Constellation-X mission's baseline microcalorimeter detector has a 2.6-arcmin field of view. A field of view of 8-arcmin or more would greatly increase the capability of Constellation-X in areas such as studies of clusters of galaxies and supernova remnants,

surveys of the cosmic x-ray background and nearby galaxies, and the number of serendipitous sources discovered. We are developing a microcalorimeter detector that uses two thermometers located at the ends of a long absorber to do one-dimensional imaging spectroscopy. This device is called a Position-Sensitive Transition-Edge Sensor (PoST), and can increase the field of view by a factor of 5–10 over current single-pixel designs. These detectors have already achieved an energy resolution of 9-eV FWHM at 6~keV, and have a theoretical resolution of around 3~eV FWHM. In this poster we present the current state of the art for this detector technology, as well as a concept for a hybrid microcalorimeter using a 10×10 "hot core" of fast, high energy resolution single pixel detectors surrounded by a large array of PoSTs.

Highlights of Constellation-X Reflection Grating Spectrometer Technology Development

K. Flanagan (MIT), W. Cash (University of Colorado), R. Heilmann (MIT), G. Prigozhin (MIT), A. Rasmussen (SLAC), G. Ricker (MIT), M. Schattenburg (MIT), A. Shipley (University of Colorado)

Constellation-X is a high-throughput high-resolution spectroscopy mission and a Great Observatory of NASA's *Beyond Einstein* program. The Reflection Grating Spectrometer (RGS) aboard Constellation-X provides high-resolution X-ray spectra over 0.25-2.0 keV. The instrument's two components (a grating array and a detector readout array) each require significant technological advances to meet the Constellation-X requirements for effective area and spectral resolution. We review the technology status, recent achievements and challenges of the Con-X Reflection Grating Spectrometer.

The Con-X Hard X-Ray Telescope and its angular resolution

Paul Gorenstein and Suzanne Romaine
Harvard-Smithsonian Center for Astrophysics
Cambridge, MA 02138

The Constellation X-Ray Mission's instruments include a focusing telescope called the HXT whose bandwidth extends to ~ 70 keV. One of its functions is providing an unambiguous measure of the continuum of sources whose spectra are predominantly thermal but whose interpretation requires detailed knowledge of the continuum. This is particularly important for objects where scattering or gravitational red shifts have resulted in line broadening. Also, the hard X-ray band is important on its own in the study of the non-thermal processes that dominate the emission from AGNs and other objects. At least two different methods of constructing the HXT mirrors are being investigated. Both are a dense set of concentric Wolter 1-like substrates that use multilayer reflective coatings. They differ in their method of producing and aligning mirror substrates and may well differ with respect to mass, effective area and angular resolution. Essentially all exposures of the HXT will be background limited. With a mass limit set by spacecraft accommodation being the principal constraint, highest sensitivity not highest effective area, the current selection criterion, should be the basis for selecting the HXT configuration from among the various options. The sensitivity is essentially the ratio of the effective area to the angular resolution. This work was supported in part by NASA Grant NNG05WC27G.

Soft x-ray reflection grating technology development for Constellation-X

Ralf K. Heilmann, Mireille Akilian, Chih-Hao Chang, Juan C. Montoya, Yong Zhao, and Mark L. Schattenburg

The Constellation-X mission design calls for a soft x-ray Reflection Grating Spectrometer (RGA) with light-weight reflection gratings placed in the converging beam of the Spectroscopy X-ray Telescope (SXT). Our early demonstration of high-efficiency saw-tooth reflection gratings for an in-plane diffraction geometry fabricated from off-cut anisotropically-etched silicon wafers was recently supplemented by the fabrication of high-efficiency gratings with parameters (grating period, blaze angle) suitable for an extreme off-plane mount.

Patterning of large-area reflection gratings is efficiently done through Scanning Beam Interference Lithography (SBIL) on our so-called Nanoruler tool.

Resolution goals require 2 arcsec or better flatness for 100-200 mm long and ~ 0.5 mm thick thin-foil grating substrates. We designed and built an ultra-low-stress thin-foil metrology truss that allowed us to surpass this flatness requirement in combination with flattening via Magnetorheological Finishing (MRF).

Multiplexed x-ray microcalorimeters with improved energy resolution for Constellation-X

K. D. Irwin, J. A. Beall, W. B. Doriese, W. D. Duncan, L. Ferreira, G. C. Hilton, C. D. Reintsema, D. R. Schmidt, J. N. Ullom, L. R. Vale, Y. Xu, B. L. Zink

NIST is working with NASA/Goddard Space Flight Center (GSFC) to develop multiplexed x-ray microcalorimeter arrays optimized for the Constellation-X mission. These arrays are based on superconducting transition-edge sensors (TES) read out with multiplexed superconducting quantum interference device (SQUID) amplifiers. We present recent progress in improving the x-ray energy resolution through engineering the device geometry, and present recent results with 8- and 16-channel multiplexers.

In order to achieve the ambitious x-ray energy resolution goals for the Constellation-X microcalorimeters, we have conducted extensive investigations of the high-frequency unexplained noise in TES sensors as a function of operating resistance, current density, applied magnetic field, and device geometry. Using the measured dependencies of the unexplained noise, we have optimized the design of our TES x-ray sensors and achieved FWHM energy resolutions of 2.4 eV at the 5.9 keV Mn Kα complex, which is a significant step towards the Constellation-X resolution goal of 2 eV at 5.9 keV.

We also present progress in the development of time-division SQUID multiplexers for the readout of large x-ray calorimeter arrays. We present results from x-ray microcalorimeters in 8- and 16-channel multiplexers. We describe the constraints on the system architecture, and present a practical design for a 32-channel MUX to be used in a kilopixel array.

Finally, we have extended this work to develop TES microcalorimeters for higher energy applications, such as the study of Ti emission lines from supernova remnants, including high-resolution velocity diagnostics. We have obtained a spectral resolving power of 4300 (energy/half-energy width) at the 103 keV Gd γ-ray line using a TES with a Sn absorber.

We are grateful for technical support from the NASA/GSFC microcalorimeter group, and for financial support from NASA through the Constellation-X program and Grant NDPR S06561-G.

Requirements, Goals and Challenges for an X-Ray Microcalorimeter Spectrometer on the Constellation-X Observatory

Rich Kelley

X-ray microcalorimeter arrays are well suited to address key problems in high-energy astrophysics. Their high spectral resolution, high quantum efficiency and imaging capability provide a powerful new tool for astrophysicists. These features have made the microcalorimeter a key component of the Constellation-X mission. Building on the potential and demonstrated performance in orbit of the JAXA/NASA high resolution X-Ray Spectrometer on Suzaku (formerly Astro-E2), plans are underway to implement much larger arrays of microcalorimeters with higher spectral resolution and optimal pixel design to match the x-ray mirror performance. A 2.5' array with 5" pixels that have a resolving power > 2600 at the Fe-K shell energy (6 keV) is the starting point for possible designs, and would enable new capabilities for measuring the properties of all classes of celestial sources, including those with extended x-ray emission. The low temperatures required for microcalorimeter performance will be achieved by using multiple, cryogen-free cooling stages designed to operate for many years in space. We will present the basic design requirements, goals and technical roadmap for the Constellation-X X-Ray Microcalorimeter Spectrometer (XMS).

High-density arrays of x-ray microcalorimeters for Constellation-X

C.A. Kilbourne, S.R. Bandler, J.A. Chervenak, E. Figueroa-Feliciano, F.M. Finkbeiner, N. Iyomoto, R.L. Kelley, F.S. Porter (NASA/GSFC), T. Saab (U. Florida), J. Sadleir (NASA/GSFC and U. Illinois)

We have been developing x-ray microcalorimeters for the Constellation-X mission. Devices based on superconducting transition edge sensors (TES) have demonstrated the potential to meet the Constellation-X requirements for spectral resolution, speed, and array scale (> 1000 pixels) in a close-packed geometry. In our part of the GSFC/NIST collaboration on this technology development, we have been concentrating on the fabrication of arrays of pixels suitable for the Constellation-X reference configuration. We have fabricated 8x8 arrays with 0.25-mm pixels arranged with 92% fill factor. The pixels are based on Mo/Au TES and Bi/Cu absorbers. We have achieved a resolution of 4.9 eV FWHM at 6 keV in such devices. Studies of the thermal transport in our Bi/Cu absorbers have shown that, while there is room for improvement, for 0.25 mm pixels our existing absorber design is adequate to avoid line-broadening from position dependence caused by thermal diffusion. In order to push closer to the 4-eV requirement and 2-eV goal at 6 keV, we are refining the design of the TES and the interface to the absorber.

For the 32×32 arrays ultimately needed for Constellation-X, signal lead routing and heat sinking will drive the design. We have had early successes with experiments in electroplating electrical vias and thermal busses into micro-machined features in silicon substrates. The next steps will be fabricating arrays that have all of the essential features of the required flight design, testing, and then engineering a prototype array for optimum performance.

The development of high resolution silicon x-ray microcalorimeters

F.S. Porter, R.L. Kelley, C.A. Kilbourne (NASA GSFC)

Recently we have produced x-ray microcalorimeters with resolving powers approaching 2000 at 5.9 keV using a spare XRS microcalorimeter array. We attached 400 μm square, 8 μm thick HgTe absorbers using a variety of attachment methods to an XRS array and ran the detector array at temperatures between 40 and 60 mK. The best results were for absorbers attached using the standard XRS absorber-pixel thermal isolation scheme utilizing SU8 polymer tubes. In this scenario we achieved a resolution of 3.2 eV FWHM at 5.9 keV. Substituting a silicon spacer for the SU8 tubes also yielded sub-4eV results. In contrast, absorbers attached directly to the thermistor produced significant position dependence and thus degraded resolution. Finally, we tested standard 640um-square XRS detectors at reduced bias power at 50mK and achieved a resolution of 3.7eV, a 50% improvement over the XRS flight instrument. Implanted silicon microcalorimeters are a mature flight-qualified technology that still has a substantial phase space for future development. We will discuss these new high-resolution results, the various absorber attachment schemes, planned future improvements, and, finally, their relevance to future high-resolution x-ray spectrometers including Constellation-X.

Event Driven X-ray CCD Detector Arrays for the Reflection Grating Spectrometer on the Constellation-X Mission

Ricker, G.R., Doty J.P., Kissel S.E., Prigozhin, G.Y.

The Reflection Grating Spectrometer (RGS) on Constellation-X will provide very high spectral resolution in the low energy X-ray band below 2 keV, where most atomic features are located. A baseline value for the RGS of $E/\Delta E > 300$ is planned, with values of $E/\Delta E \sim 3000$ being discussed as a possible goal for an off-plane grating design. Thus, the RGS will complement Constellation-X's X-ray microcalorimeter, which has its highest spectral resolution at energies greater than 2 keV. The Reflection Grating Spectrometer Focal Plane Camera (RFC) reads out the RGS spectra by means of a long array of extended low-energy response, event-driven silicon CCDs (EDCCDs). The current instrument baseline calls for coverage of the X-ray energy (wavelength) range from 0.25 to 2 keV (6–50 Å) in an elongated, multi-CCD array. The back-illuminated EDCCD can accommodate these goals, by providing rapid frame rates (~30 Hz) at non-cryogenic temperatures (~ –20C or higher), for power requirements ~100× less than for conventional CCDs. The status of both the RFC detector and array technologies will be presented.

Development of Prototype Nickel Optic for the Constellation-X Hard X-Ray Telescope

Suzanne Romaine

The Constellation-X mission planned for launch in 2015, will feature an array of Hard X-ray telescopes (HXT) whose bandwidth extends to ~ 70 keV. Several technologies are being investigated for fabrication of these optics, including multilayer Coated Electroformed-Nickel-Replicated (ENR) shells.

We are building a prototype HXT mirror module using an ENR process to fabricate the individual shells. This prototype consists of 5 shells with diameters ranging from 150 mm to 280 mm with a length of 426 mm.

This paper presents a progress update and focuses on accomplishments during this past year. In particular, we will present results from high-energy full illumination tests, taken at the MPE Panter Test Facility. This work was supported in part by NASA Grant NNG05WC27G and NASA/CONX grant 44A-1046805.

Efficiency of a Grazing Incidence Off-Plane Grating in the Soft X-Ray Region

J. F. Seely, J. M. Laming (NRL), L. I. Goray (I.I.G. Inc.), B. Kjornrattanawanich, G. E. Holland (NRL), K. A. Flanagan, R. K. Heilmann, C.-H. Chang, M. L. Schattenburg (MIT), A. P. Rasmussen (Stanford Univ.),

We report on efficiency measurements of a grazing incidence diffraction grating in the off-plane mount, performed using polarized synchrotron radiation on the NRL beamline at Brookhaven National Laboratory/NSLS. The grating had 5000 grooves/mm, an effective blaze angle of 14 degrees, and was gold coated. The efficiencies in the two polarization orientations (TM and TE) were measured in the 1.5 nm to 5.0 nm wavelength range and were compared to the efficiencies calculated using the PCGRATE-SX grating simulation code of Goray and coworkers. The TM and TE efficiencies differ, offering the possibility of performing unique science studies of astrophysical, solar and laboratory sources by exploiting the polarization sensitivity of the off-plane grating.

Advances in NTD Germanium-Based Microcalorimeters For Soft and Hard X-Ray Spectroscopy on Constellation X

E. Silver and G. Austin (CfA), J. Beeman and D. Landis (LBNL), E.E. Haller (UCB), N. Madden (LLNL)

We report recent advances in our NTD germanium-based microcalorimeters that result inan energy resolution of 3 eV FWHM for 6 keV x-rays. We have developed a detailed model, which indicates that further minor improvements will realize 2 eV FWHM at 6 keV and well under 2 eV at 1 keV. Adapting these technological improvements to microcalorimeters optimized for hard x-rays will make it possible to achieve quantum efficiencies greater than 50% at 60 keV while maintaining an energy resolution of 50 eV or better. Incorporating these advances into microcalorimeter arrays will be discussed.

Lightweight X-ray Mirrors for the Constellation-X Mission

William W. Zhang, David A. Content, John P. Lehan, Robert Petre, and Timo Saha
NASA Goddard Space Flight Center
Mikhail V. Gubarev, William D. Jones, and Stephen L. O'Dell
NASA Marshall Space Flight Center
Paul B. Reid
Smithsonian Astrophysical Observatory

The Constellation-X mission presents several technical challenges, one of which is the production of X-ray mirrors. These mirrors, when measured with a comprehensive

metric combining mass, angular resolution, and production cost, go far beyond the state of the art of X-ray optics achieved by the Chandra, XMM/Newton, and Suzaku missions. To meet this challenge, we have mounted a rigorous and intense mirror development program in the past several years, and have overcome a number of technical difficulties. Now we are close to mastering a new technique that will meet, and likely exceed, the baseline mission requirements in terms of mass, angular resolution, and production cost. In this poster, we will describe in detail the mirror manufacture technique and report on the status and progress of this development program

SCIENCE POSTER ABSTRACTS

The High Redshift Universe with Constellation-X

F.E. Bauer (Columbia), D.M. Alexander (IoA), G.T. Richards (JHU), D. Stern (JPL), W.N. Brandt (PSU), S.C. Gallagher (UCLA), A.E. Hornschemeier (GSFC), R. Mushotzky (GSFC)

The deepest Chandra and XMM-Newton surveys have directly resolved ~90% of the 0.5-6 keV CXRB and ~50% of the 6-12 keV CXRB (Worsley et al. 2005), uncovering an order of magnitude higher AGN source density than found at optical wavelengths (e.g., ~7200/sq.deg; Bauer et al. 2004). The deepest >10 keV observations of the Universe have only resolved ~3% of the CXRB at its ~20-50 keV peak (Krivonos et al. 2004). These sources are so X-ray faint, that in general there is very little we can do with the current generation of X-ray telescopes to characterize them spectroscopically (and thus ascertain their true astrophysical nature). However, Constellation-X, with its large gain in collecting area and spectroscopic capability, will enable both source classifications and redshifts.

Beyond the iron K alpha emission line and the reflection component (which peaks at 20-30 keV) the hard X-ray spectra of AGN are dominated by the Compton upscattered component. Since there are currently no reliable measures of the high-energy Compton cutoff in quasars, the sensitive 10-40 keV hard energy coverage of Constellation-X will provide new insights into our understanding of the state and structure of X-ray emitting accretion-disk coronae (e.g., Sobolewska, Siemiginowska, & Zycki 2004; Zdziarski & Gierlinski 2004). For high-redshift quasars where we can probe rest-frame energies of 100-300 keV (and perhaps as high as 600 keV), we can expect to see the high-energy cutoff (50-200 keV) in some cases, thus allowing a determination of the electron temperature and optical depth of the Comptonizing plasma.

High Energy Stellar and Protostellar Physics with Constellation-X

Drake, J.J., Brickhouse, N.S., Feigelson, E.D., Guedel, M., Laming, M, Schulz, N.S.

Star and planet formation, the evolution of planetary atmospheres, magnetic dynamo processes at work in stellar interiors, the angular momentum evolution of stars, and the origin and acceleration of stellar winds and mass loss are all manifest in, or dependent on, the processes at work in the X-ray emitting outer atmospheres of stars. High energy phenomena in non-degenerate stars and protostars also offer prototypical examples of plasma and processes that occur on much larger scales in the more distant cosmic X-ray sources---from magnetic reconnection and flares illuminating accretion disks of black holes from active galactic nuclei down to X-ray binaries, to the radiatively-driven winds

and outflows of these accretion disks, to the hot and tenuous optically-thin plasma of galactic interstellar media and clusters of galaxies.

Here we describe why Constellation-X will provide a leap forward in our understanding of High Energy Stellar Physics, from magnetic dynamos in stars and brown dwarfs, to stellar surface magnetic fields and coronal structure, flares and energy storage and release, the role of energetic processes in star and planet formation, and the processes at work in the winds of OB stars.

The Warm-Hot Intergalactic Medium as seen by Constellation-X

Nicastro Fabrizio, Mike Shull, FBS Paerels, Ann Hornschemeier, Mike R. Garcia

We present detailed simulations of the Warm-Hot Intergalactic Medium (WHIM) with the gratings of Constellation-X. Simulations are based on the extrapolation of the expected number density of OVII WHIM systems from hydrodynamical simulations of the local Universe, up to redshift of z=1 and down to an OVII column density of 10^{14} cm^{-2}, and assume random metallicity and internal turbulence velocities between 0.05-0.3 Solar and 0-150 km s^{-1} respectively. We simulated 100 ks Constellation-X/gratings exposures using a relatively bright (0.5-2 keV flux of 0.1 mCrab) quasar at z=1 as background X-ray source. About 30 of such sightlines are available in the RASS. We show that about 20-30 percent of the expected OVII-WHIM systems will be detected in OVII K-alpha along one of these lines of sight with a grating resolving power of R=300, while this fraction rises to about unity with a resolving power of R > 3000 (sufficient to resolve the O lines in gas with a temperature of about 1e6 K). A resolving power of R=3000 will also allow us to detect the associated OVIII Ly-alpha lines and so to estimate a metallicity-independent ionization correction for most of the systems. We also explored a grating configuration that covered up to 60 A in wavelength, so to include the CV K-alpha spectral region, and estimated that C/N, C/O and O/N relative metallicity studies can be performed on about half of the expected systems with a resolving power of R=3000, but only for about 1-5 percent of the systems at a 10 times lower resolving power.

X-rays and Planet Formation

E. D. Feigelson (PSU)

Planets form in cold circumstellar disks that cannot emit X-rays. Nonetheless, X-ray band studies may have profound implications for the physical processes of planet formation in several ways. Observations of young stellar clusters, such as the recent Chandra Orion Ultradeep Project (COUP), demonstrate that all pre-main sequence stars produce powerful magnetic reconnection flares during the planet formation era. Calculations indicate that the X-rays can penetrate deeply into protoplanetary disks and will be the dominant source of gas ionization. COUP observations of fluorescent line emission in heavy disk stars and soft X-ray absorption in proplyds demonstrate that disk irradiation by X-rays does in fact occur. This may induce MHD turbulence in disk gases, which may substantially affect planetesimal growth and protoplanet migration. X-ray flares or associated shock waves may flash melt dust balls into chondrules, and spallation by energetic flare particles may generate short-lived radioactive isotopes that are prevalent in the meteoritic record. X-ray surveys are also useful for locating older stellar systems where the protoplanetary disk is dissipating but magnetic flaring continues. Infrared studies of such systems show a great diversity of older disk properties.

The planned Constellation-X mission will propel all of these investigations in powerful ways. For example, reverberation mapping of fluorescent line emission following flares could give unique insights into the structure of the gaseous components of protoplanetary disks.

Measuring the Fundamental Properties of Hot Gas, X-ray Binaries and ULXs in Starburst Galaxies with Constellation-X

D. Strickland & A. Ptak

We demonstrate the capability of Constellation-X to revolutionize our understanding of fundamental aspects of massive star physics, in particular mechanical energy "feedback" from massive stars into the ISM and the physics of X-ray binaries, the nature of the mysterious ultraluminous X-ray sources and the contribution of star-forming galaxies to the X-ray background.

Starburst-driven superwinds have been established to be a ubiquitous phenomenon in strongly star-forming galaxies at all redshifts. The majority of the energy and newly synthesized heavy elements in such outflows is hidden in the hot X-ray emitting gas ($10^6 \leq T$ (K) $\leq 10^8$). Current X-ray observations lack the spectral resolution necessary to robustly constrain the ionization states, absolute elemental abundances and kinematics of the multi-phase hot gas. We present some illustrative examples of how the Constellation-X calorimeter will measure these properties for the first time.

Hard X-ray telescope (HXT) observations will detect the hard ($E > 10$ keV) X-ray emission of ultraluminous X-ray sources (ULXs) and high-mass X-ray binaries which dominate the $E > 2$ keV emission of starburst emission. These observations will determine to what extent the hard X-ray power-law and its cut-off energy are consistent with Galactic X-ray binaries, particularly black hole candidates. He-like Fe-K emission lines have been detected in the X-ray spectra of nearby starburst galaxies, which may be due to either a low-luminosity AGN or hot gas at temperatures of $> 2 \times 10^7$ K. The imaging capability of the HXT will resolve the emission of the brightest X-ray binaries, allowing the contribution of hot gas and/or a low-luminosity AGN to be isolated. The HXT observations also promise to reveal the presence of a component due to inverse-Compton scattering of IR photons off of relativistic electrons. Establishing the demographics of these components will determine their contribution to the hard X-ray background.

Cosmic Feedback: Constraining AGN Outflows

S. C. Gallagher (UCLA), P. M. Ogle (SSC), D. M. Alexander (IoA), G. T. Richards (Johns Hopkins), W. N. Brandt, G. Chartas (Penn State), A. E. Hornschemeier (GSFC), T. Yaqoob (Johns Hopkins)

Over cosmic time, a significant fraction of the energy from massive black-hole accretion could have been converted into kinetic energy by large-scale outflows, affecting the host galaxies by triggering star formation (by shocking or compressing the interstellar medium [ISM]), or perhaps even shutting it down (by clearing gas from the hosts). Indeed, current large-scale structure simulations require AGN 'feedback' to regulate the growth of massive galaxies. X-rays provide a penetrating probe of all of the material in an outflow, from cool dust through to highly ionized gas. From current X-ray studies of outflows from luminous AGNs, it is evident that only high velocity X-ray photoionized outflows can carry enough mass and kinetic energy to affect the ISM significantly. Constellation-X spectroscopy will enable the crucial measurements of accretion-related mass-outflow rates needed to determine their importance in massive galaxy evolution.

This work is supported by NASA.

Constraining the Progenitors and Explosions of Supernova Remnants with Constellation-X

U. Hwang, J. P. Hughes, C. Badenes, E. Feigelson, F. Paerels, R. Petre, N. Schulz, M. Shull, P. Slane, R. Smith, & S. Snowden

Constellation-X will provide dramatically improved data for young, ejecta-dominated supernova remnants that should lead to important new insights into the physics of supernova explosions, shocks, and the pre-supernova evolution of the progenitor systems. Combined good angular and spectral resolution in the 0.25-10 keV bandpass are critical to unraveling the complex distribution, dynamics, and thermal history of the ejecta in the remnants of both core-collapse and thermonuclear (Ia) supernovae. The high sensitivity of Con-X will reveal the distribution of emission from low-abundance nucleosynthesis products (e.g., Ti, V, Cr, Mn, and Co), and faint inner-shell excitation lines from nuclear decay products that will provide clues as to the details of the explosion mechanism. The hard X-ray lines associated with ^{44}Sc decays will also provide important constraints on supernova nucleosynthesis. For thermonuclear supernovae, modeling of the X-ray emission from ejecta can set tight constraints on the progenitor system and explosion mechanism, as will sensitive limits on the detection of emission from the low-density circumstellar medium. Other important measurements that Con-X will enable include directly determining the allocation of shock energy between electrons and ions through comparison of electron temperatures and shock velocities determined from thermal line widths, and establishing the expansion profile of ejecta in remnants with pulsar wind nebulae.

Studying Cosmic Feedback with Constellation-X

B.R. McNamara, M. Begelman, M. Donahue, M. Voit

X-ray observations of galaxies, groups, and clusters made with the Chandra observatory have shown that outbursts from active galactic nuclei (AGN) have a dramatic impact on the thermodynamic history of the hot gas in these systems. Releasing upward of 10^{61} erg into the intracluster medium, AGN-driven outflows can heat and redistribute the hot gas on scales of hundreds of kiloparsecs. They can regulate or quench so-called cooling flows, and perhaps supply the excess entropy (preheating) in groups and clusters. The history of AGN feedback can be traced over cosmic time using measurements of giant cavity systems in the hot gas, and by probing the entropy of the hot gas in distant clusters. We evaluate the ability of Constellation-X to study clusters beyond redshift 1, and to trace the history of feedback over the ages of clusters.

Revealing Intermediate Mass Black Holes with Constellation-X

Jon Miller (U Michigan)

From Population-III stars seeding galaxies with intermediate mass black holes at the epoch of galaxy formation, to the evolution of globular cluster and young stellar clusters, the broad potential importance of intermediate-mass black holes is now being realized in full. Recent results from Chandra and XMM-Newton have revealed potential evidence for intermediate-mass black holes, in a set of the most luminous "ultra-luminous" X-ray sources in nearby normal galaxies. Observations with HST have also revealed possible evidence for intermediate-mass black holes, in the centers of some globular clusters.

Constellation-X is ideally suited to decisively weigh-in on the existence or absence of intermediate mass black holes in the present-day universe. This poster will discuss how simple observations with Constellation-X can fully reveal this new class of relativistic objects.

Probing dark energy with Constellation-X

D. Rapetti, S. Allen

Con-X will carry out two powerful and independent sets of tests of dark energy based on X-ray observations of galaxy clusters. The first group of tests will measure the absolute distances to clusters, primarily using measurements of the X-ray gas mass fraction in the largest, dynamically relaxed clusters, but with additional constraining power provided by follow-up observations of the Sunyaev-Zel'dovich (SZ) effect. As with supernovae studies, such data determine the transformation between redshift and true distance, d(z), allowing cosmic acceleration to be measured directly. The second, independent group of tests will use the spectroscopic capabilities of Con-X to determine scaling relations between X-ray observables and mass. Together with theoretical models for the mass function and X-ray and SZ cluster surveys, these data will help to constrain the growth of structure, which is also a strong function of cosmological parameters.

Con-X data will constrain dark energy with comparable accuracy and in a beautifully complementary manner to the best other techniques available circa 2018. For example, with a modest ~10-15% (10-15 Ms) investment of the available observing time over the first 5 years of the Con-X mission, we will be able to measure the X-ray gas mass fraction (or predict the Compton y-parameter) to 5% or 3.5% accuracy for 500 or 250 clusters, respectively, with a median redshift $z \sim 1$. When combined with CMB data, the predicted dark energy constraints from Con-X X-ray gas mass fraction data are comparable to those projected by the SNAP collaboration for CMB+SNAP data as well as the predictions for future galaxy redshift surveys. Only by combining such independent and complementary methods can a precise understanding of the nature of dark energy be expected to be achieved.

Probing strong gravity and extreme astrophysics around black holes with Constellation-X

C.S.Reynolds, A.J.Young, A.C.Fabian, and the Con-X AGN Science Team

Some black hole systems display a relativistically broadened iron emission line in their spectrum, presumably due to fluorescence in the surface layers of the inner regions of the accretion disk. Constellation-X will allow us to observe variability in this line due to the orbital motions of inhomogenieties in the disk as well as reverberation effects (i.e., the light echo of short/intense flares across the accretion disk). We will show how these phenomena can be used as a quantitative probe of black hole mass, spin and (possibly) the validity of General Relativity.

Neutron Star Equation of State: What Constellation-X Might Tell Us

D Sanwal (JHU/GSFC), T Strohmayer, J Cottam (NASA/GSFC),
F. Paerels (Columbia University), MC Miller, S Bhattacharyya (UMD),
D. Chakrabarty (MIT)

The Equation of State (EOS) of cold matter beyond nuclear density remains one of the most outstanding unsolved problems in fundamental physics. Cold matter beyond nuclear density may be dominated by exotic components such as hyperons, quark matter, and condensates, or it could be primarily composed of nucleons. Such extreme physical conditions are largely inaccessible in terrestrial labs, but can be probed using precise measurements of neutron star masses and radii. Recent X-ray observations have provided new spectral and timing signatures from the surfaces of neutron stars–including atmospheric lines and pulsation signals–that are providing new probes of neutron star structure, but precise characterization of the properties of neutron stars is not yet within reach. Advances in observing capabilities are required to fully exploit these. The Constellation-X mission will provide the high spectral resolution, large collecting area and time resolution required to allow us to measure the mass and radius of many neutron stars using a variety of techniques. We will discuss methods for constraining the neutron star EOS and the prospects of advancement in our knowledge of the EOS with NASA's Constellation-X mission in the light of recent observations and theoretical modeling efforts.

High resolution x-ray spectroscopy on Constellation-X

E. Schindhelm, W. Cash and N. Arav

High resolution X-ray spectroscopy is crucial to studying the warm absorber in AGN outflows, as evidenced by the dynamical structure seen in high quality UV data. Partial covering of the central emission source by the out-flowing gas plays a critical role in UV line formation, and may be important in the X-ray absorber. We have studied the best X-ray data set of an AGN outflow, the Chandra 900 kilosecond observation of NGC 3783, for the effects of covering factor in the strongly saturated line series of Ne X and O VII. Due to the limited resolution and signal to noise around 1 keV, it is difficult to determine a correct model for absorption line formation. Simulations show a resolution of ~3000 is necessary to do this. The reflection grating spectrometer onboard the future Constellation X mission can accomplish such resolution, however the off-plane mount is needed. Current studies of the off-plane look promising, with test gratings achieving high throughput and resolution.

X-Ray Survey of Interstellar Media with Constellation-X

N.S.Schulz. J.M. Juett, C.R. Canizares

High-resolution X-ray spectra obtained with the *Chandra X-ray Observatory* demonstrated the feasibility to study chemistry, abundance and ionization fraction of various phases of the interstellar Medium (ISM). These include the cold, warm, and hot ISM phases. The measurements allow the determination of the optical depths of the photoelectric absorption edges specifically from O, Ne, Mg, Si, S, and Fe as well as equivalent widths of resonance absorption line from atoms, ions, and molecules. While *Chandra* is limited to observations of the brightest continuum sources within the galactic plane and bulge as well as less than half a dozen of extragalactic sources, *Constellation-X* will provide the survey capacity we need to study interstellar media, galactic and extragalactic, with the necessary sensitivity and resolution. In the poster we present current results with *Chandra*. We also lay out future survey strategies with *Constellation-X*.

High-Resolution Spectroscopy of the Diffuse ISM with Constellation-X

R. Smith

It is now unquestioned that X-ray observations provide a useful approach to ISM studies, not only the hot ISM but cool gas seen in absorption, dust grain scattering, as well as shock/cloud interactions. Chandra and XMM/Newton have begun this work but are hampered by the (relatively) low effective area and spectral resolution available for diffuse sources. We discuss how Constellation-X will be able to dramatically improve studies of the ISM. We will show how: (1) High-resolution and large effective area absorption spectroscopy can be used to study IS gas motions, abundances, and ionization balance, (2) Non-dispersive spectroscopy can study shock/cloud interactions to disentangle the processes by which SN ejecta mix into the ISM while simultaneously heating it, and (3) Dust grain composition and distribution can be measured both in absorption and emission (via dust-scattered halos)

Contribution of Constellation-X to the Cosmological Work with High-Redshift Galaxy Clusters"

A. Vikhlinin

We will discuss how information provided by observations of high-redshift galaxy clusters with Constellation-X could enhance the accuracy of the dark energy constrains provided by large-area cluster surveys.